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Comparisons of the North Polar Cap of Mars and the Earth's Northern Hemisphere Snow Cover

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ABSTRACT

The boundaries of the polar caps of Mars have been measured on more than 3000 photographs since 1905 from the plate collection at the Lowell Observatory. For the Earth the polar caps have been accurately mapped only since the mid 1960's when satellites were first available to synoptically view the polar regions. The polar caps of both planets wax and wane in response to changes in the seasons, and interannual differences in polar cap behavior on Mars as well as Earth are intimately linked to global energy balance. In this study data on the year to year variations in the extent of the polar caps of Mars and Earth were assembled and analyzed together with data on annual variations in solar activity to determine if associations exist between these data. It was found that virtually no correlation exists between measurements of Mars north polar cap and solar variability. An inverse relationship was found between variations in the size of the north polar caps of Mars and Earth, although only 6 years of concurrent data were available for comparison.

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INTRODUCTION

Mars is slightly more than half the size of the Earth and revolves in an orbit lying between Earth and Jupiter. It is a dynamic world with many Earth-like characteristics including varying climates, polar ice caps and a complex geomorphology. The polar caps of Mars are conspicuous in telescopic views because of the large albedo contrast between the polar ice deposits and the surrounding ice-free surface. The polar caps were probably first observed by Christian Huygens and J. D. Cassini in the mid-17th century, but William Herschel, near the end of the 18th century, was the first observer to recognize that changes in the appearance of the caps were related to seasonal changes (James and Lumme, 1982). In the late 19th and early 20th centuries, Percival Lowell made extensive observations of the Martian arctic. In Lowell's time, possibly more was known about the polar caps of Mars than those of Earth (Parker et al. 1982). During this century visual observations have continued to be an important source of data on the fluctuations of Mars polar caps. The boundaries of the north and south polar caps of Mars have been measured on more than 3000 photographs from the plate collection at the Lowell Observatory by Fischbacker et al. 1969. The caps wax and wane in response to changes in the Martian seasons. Many researchers have noted the dependence of the global weather of Mars on the behavior of the polar caps; a relationship recently confirmed by orbiting spacecraft (Parker et al. 1982). In this study annual differences in the size of Mars north polar cap were used as an index or indicator of fluctuations in the Martian climate. An attempt has been made here to determine if there is an association between variations in the size of Mars north polar cap and solar variability. Additionally, since Earth and Mars are the only bodies in our solar system which are known to have polar caps, an effort was made to see if an association exists between the variations observed in the size of their respective polar caps.

ORBITAL CONSIDERATIONS FOR VIEWING MARS

Due to the tilt of the Martian axis and the eccentricity of the Martian orbit, observations in some seasons tend to be superior to others in providing accurate polar cap measurements. Each cap is better seen during its receding phase than during its growing phase, because each cap melts during the season when it is tilted toward the Sun and, therefore, somewhat towards the Earth (Fischbacker et al. 1969).

The eccentricity of the Martian orbit is greater than that of any other planet except Mercury and Pluto, whereas the eccentricity of Earth is small, not differing much from a circle (Table 1). The difference between the distance of the closest approach of Mars to the Sun (perihelion) and the farthest distance (aphelion) is about 42.5 million kilometers compared to about 5.5 million kilometers for Earth. It takes Mars approximately 687 days to make one complete orbit of the Sun. For Earth, one orbit takes about 365 days. The greater length of the Martian year is caused by the larger orbit and its lower average speed (Ley et al. 1956) (Table 1).

The time between two successive similar alignments of Mars with the Sun as seen from the Earth is termed the synodic period. The synodic period may refer to either two conjunctions or two oppositions of Mars, Earth and the Sun (Figure 1), however, Mars cannot be observed at conjunction as it is then in the same direction as the Sun. The observed intervals between successive oppositions ranges from 763 to 810 days with an average value of about 780 days. Thus, Mars can be most easily observed approximately every 2 years and 50 days when Earth and Mars are closest (Glasstone, 1968).

Because the eccentricity of the orbit of Mars is significantly greater than that of Earth's orbit, the distance between the two planets varies from one opposition to the next (Figure 2). The distance between the two planets ranges from somewhat less than 56 million kilometers at the most favorable opposition to more than 101 million kilometers at the least favorable opposition. Since the Earth has a smaller orbit than Mars and travels faster, Earth catches-up with Mars before opposition and moves away from Mars following opposition. As a result, there is a period of only a few months on each side of opposition when conditions are optimal for studying Mars (Glasstone, 1968). Because oppositions occur on the average at intervals of more than 2 years, it is evident that opportunities for studying the Martian polar caps are quite restricted.

Mars, like Earth, rotates about a north-south axis inclined at an angle of 25° to a line perpendicular to the orbit plane. Although the angle of inclination of the axes of Earth and Mars are very similar, the two axes point in different directions in space. An angle of about 45° is formed by the different directions of the two axes (Glasstone, 1968). So, just as the inclination of the Earth's axis determines the best locations from which to observe Mars, the inclination of the Martian axis determines the parts of Mars that can be observed at various oppositions (Figure 3).

From Figure 3 it can be seen that at perihelic (favorable) oppositions, when Earth's north pole is tipped toward the Sun, the north pole of Mars is tipped away from the Sun and Earth. Consequently, at perihelic oppositions, the northern latitudes of Mars will not be visible from Earth, although the Martian south pole can be readily observed, especially from Earth's southern hemisphere. Conversely, at aphelic (unfavorable) oppositions, the high northern latitudes of Mars can be seen from the northern hemisphere of Earth, but the south pole of Mars will not be visible.

Because of the angle between the directions in which the axis of Mars and Earth point, it happens that the line passing through the position of Mars at its equinoxes is nearly at right angles to that for Earth (Figure 4). So when Mars and Earth are close to one another, near an opposition, when it is September 23 on Earth, for example, then winter will just be starting on the northern hemisphere of Mars. Similarly, when it is middle or late autumn on Earth, the northern hemisphere of Mars will be approaching the spring equinox (Table 2) (Glasstone, 1968).

MARS POLAR CAPS AND CLIMATE

During local winter on Mars, a white cap develops over the poles. For most of the winter, the cap appears to be covered by a white cloud or hood, but just before the local spring equinox the hood disappears and the sharp outline of the cap can be detected. Subsequently, during the spring, the size of the polar caps decrease and generally reaches a minimum near the beginning of local summer.

The south polar cap of Mars is much more extensive than the northern cap since winter in the southern hemisphere is longer and colder than in the northern hemisphere. Conversely, summer is warmer in the southern hemisphere of Mars than in the northern hemisphere and thus the southern polar cap recedes much faster, in spite of its larger size, and frequently disappears during local summer, whereas the northern cap has never been known to completely disappear. The northern polar cap does not often extend south of 60°N, however, the southern cap typically reaches as far as 50°S (Glasstone, 1968). The extent of the polar caps of Mars, relative to its size, is similar to that of Earth; at the end of winter the terrestrial snow cover reaches about 50°N. When a polar cap on Mars starts to recede, its outer rim becomes ragged as some parts of the cap are seen to project farther than others, leaving protrusions which later become detached from the main polar cap. As summer approaches, dark rifts appear at various locations throughout the cap. These darker areas increase in size and result in the cap breaking-up into a number of remnant regions which continue to decrease in size. The cap recession does not always proceed at a constant rate. The sublimation accelerates in mid spring and then the retreat of the cap slows down and may stop. During some years, the cap has even been observed to increase slightly in diameter before finally shrinking (Capen and Parker, 1981).

The composition of the polar caps may explain the irregularities which are often observed in the regression of the caps. The north polar cap of Mars consists of a thin mantle of carbon dioxide (CO_2) crystals underlain by a small thick ice (H_2O) cap (Capen and Capen, 1970). The CO_2 component steadily evaporates as spring progresses, but the regression of the remaining water ice, with its higher sublimation temperature, occurs more slowly and unevenly (Parker et al. 1982). A spectroscopic study of the variations in atmospheric CO_2 abundance and surface pressure of Mars by Barker (1969) has shown a strong correlation between a maximum CO_2 abundance and a minimum size of the polar caps, and a decrease in CO_2 abundance during the period when the cap is reforming. Table 4 presents the atmospheric composition of Mars and Earth.

The thickness of the Martian polar caps has been estimated by Vaucouleurs (1954) among others by comparing the rate of recession during the spring with the heat absorbed from the Sun. It is concluded that the depth of the H_2O and CO_2 deposits is most likely only a few centimeters (Vaucouleurs, 1954; Sagan, 1971). But under the lesser gravity on Mars, deposits of crystals may add up to a somewhat thicker layer (Vaucouleurs, 1954). This relatively shallow veneer probably does not cover the surface completely and uniformly and possibly accounts for the small value of the apparent albedo for the Martian polar caps of 0.5 compared to an albedo of 0.8 for a thick layer of fresh snow on Earth (Glasstone, 1968). Additionally, deposits of fine dust resulting from global dust storms would reduce the surface reflectivity.

It has been theorized that at higher latitudes on the north polar cap, ice deposits are much deeper than at more southerly locations. Sagan (1972) considered that 'frost' evaporating in the summer sun near the edge of the cap would perhaps be partially redeposited on the remnant cap which he estimated to be 1 km thick. This would account for the fact that the north polar cap has never been known to completely disappear.

Interannual differences in polar cap behavior are noteworthy because they appear to be associated with the climate of Mars. The solid CO_2 of the seasonal caps is in equilibrium with the planet's atmosphere and is thus intimately linked to the global energy balance. Data on cap boundaries are the only available historical sources that are relevant to short-period climatic changes on Mars (James and Lumme, 1982).

The length of the Martian seasons (Table 3) are approximately twice as long as those on Earth. Due to the marked eccentricity of the Martian orbit and the resulting differences in the speed of Mars as it travels around the Sun, the Martian seasons are of an unequal duration ranging from 146 days for the northern autumn (southern spring) to 199 days for northern spring (southern autumn). Although spring and summer in the northern hemisphere of Mars are considerably longer than in the southern hemisphere, temperatures are not as warm since Mars is much more distant from the Sun during summer in the northern hemisphere than in the southern hemisphere. At perihelion Mars receives about 44% more radiation than at aphelion (Glasstone, 1968).

The mean annual surface temperature on Mars was estimated to be near 225 K at the equator and about 155 K at the poles as measured by Mariner and Viking spacecraft missions (NASA, 1980). Since the Martian atmosphere contains approximately 95 percent CO_2 and a surface pressure of 6 millibars (mb), a noticeable 'greenhouse effect' should result despite the rarified atmosphere of Mars (Lyall, 1974) (Table 4). Mariner 7 data indicated surface temperatures less than 150 K in the region of the southern polar cap in spring. This is near the sublimation temperature for CO_2 (148 K), which is why it has been concluded that most of the material of the southern cap is solid CO_2. Mariner 9 observations of the residual north polar cap in mid-summer resulted in temperatures about 25 K higher (175 K); too warm for the formation of CO_2 crystals. Therefore, it is assumed that the residual polar caps are largely H_2O ice and snow. During spring and summer the polar caps were observed to be about 35 K cooler than adjacent ice-free regions (Kondratyev and Hunt, 1982).

A particularly interesting event on Mars are the annual dust storms which seem to develop during the summer in the southern hemisphere concealing much of the planet's surface. Global dust storms have significant effect upon condensate processes in the polar regions. The polar hood and the polar cap can be modified by these storms. Dust storms in 1977 appeared to significantly effect the retreat of the south polar cap (James et al. 1979). Dust can modify the polar energy balance by changing the radiative transport properties of the atmosphere, by causing meridional transport of energy into the polar region and by increasing the available number of potential condensation nuclei in the atmosphere (James, 1979).

METHOD

For this study, measurements made of the polar caps of Mars were acquired and examined between the years of 1905 and 1982. Fischbacker et al. (1969) mapped the polar caps between 1905 and 1965 using over 3000 photographs from the Lowell Observatory plate collection (Slipher, 1962). The edge of the polar cap for any given Martian date was derived by making measurements at individual meridians 10° apart in longitude so that a single photographic plate might contribute as many as 11 points defining the boundary of each cap. Because different telescopes and lens systems were used, the Martian images ranged in size from about 1 mm to 8 mm in diameter. There were also substantial differences in photographic granularity and in the viewing quality of the time the photographs had been made. For more detailed information concerning the plate mapping procedure, see Fischbacker et al. (1969).

Martian polar cap boundaries subsequent to 1965 have been mapped and measured by several observers including Capen and Capen, 1970; Capen and Parker, 1980; James, 1979; James, 1982; James and Lumme, 1982; Kyosuke and Saito, 1979; and Parker et al. 1982. In these more recent studies, due to more sophisticated instrumentation and higher quality optics, measurements are assumed to be more reliable than those from the earlier photographic plates. To chart the retreat of the polar caps, Parker et al. 1982, for example, made direct measurements with a filar micrometer attached to 32 cm f/6.5 Newtonian and a 32 cm f/16 Cassegrain telescope. The size of the polar cap was expressed as the areocentric (Mars centered) latitude so that to find the latitude of the polar caps edge, the width of the cap parallel to a latitude line was simply measured (Parker et al. 1982).

As discussed previously, each cap is better viewed during its receding phase than during its growing phase since each cap melts during the season when it is tilted somewhat toward the Earth. The Martian polar caps are near their maximum extent at about the time of the Martian vernal equinox, for the Martian arctic and the Martian autumnal equinox, for the south pole. The time at which measurements of the caps are taken is expressed, in this study, as the areocentric longitude of the Sun (ALS) in degrees, measured along the ecliptic of the Martian celestial sphere. With this system 0° is the vernal equinox, 90° is the summer solstice, 180° is the autumnal equinox and 270° is the winter solstice. This same convention is followed for Earth (Parker et al. 1982). For the Martian northern hemisphere, the regression of the polar cap is typically mapped between 0° and 150°. Figure 5 shows plots of the Mars north polar cap recession during the Martian spring from 1905–1982.

Variations in the size of the northern cap of Mars were compared with solar variability as indicated by sunspot numbers. Well defined oscillations in the number of spots appearing on the face of the Sun seem to occur over periods of about 11 and 23 years. Although periodicities of about the same lengths have been found for certain elements of climate on Earth, just how these changes in solar output effect the climate is uncertain (Miller and Thompson, 1975). It is known that sunspot number is a coarse index for specific solar inputs to the Earth and its annual average is oversmoothed in comparison to the short time scale of individual solar events and their terrestrial impacts in the upper atmosphere (Geophysics Research Board, 1982). Nevertheless, because of their long period of record and because they provide direct evidence that the Sun does vary, annual sunspot numbers are often used as an index of solar variability.

There is no obvious association between Earth's seasonal snow cover extent and solar output. It may be that there is simply no connection between the two or it may be that whatever association exists is hidden by the complex dynamic processes and interactions between the terrestrial oceans, continents and atmosphere. However, the Little Ice Age in Europe has been linked with the Spörer and the Maunder minima of solar activity from about 1410–1540 and 1645–1715 respectively, when sunspots were much less numerous than those observed anytime before or since. As previously mentioned, the Martian climate is not as complicated as that of Earth; the solid CO_2 of the seasonal polar caps are in equilibrium with the planet's atmosphere and is therefore closely connected to the Martian global energy balance. Thus it was thought that if there is a link between solar variability and polar cap extent it might be more readily detectable on Mars than on Earth. For this investigation annual sunspot numbers as observed at the Royal Greenwich Observatory in England were correlated with year to year changes in the size of the northern polar cap of Mars.

Additionally, measurements made of the Martian north polar cap were also compared with measurements of the terrestrial north polar cap which were mapped using NOAA satellite data (Matson and Wiesnet, 1981). While data are available for Mars from 1905 and earlier, remotely sensed synoptic data of the Earth's snow cover have been available only since the mid 1960's. Although ground-based snow cover measurements exist for the United States from the 1940's (Walsh et al. 1982), the snow cover extent for the entire northern hemisphere cannot be extrapolated from measurements made in the United States. Therefore, comparisons of the polar caps of Mars and Earth were made only since 1966. It should be noted that comparisons can be made only when Earth and Mars are near aphelic or intermediate oppositions, for the northern hemisphere, which unfortunately do not occur every year (Figure 3). For those years when comparisons could be made the width of the Martian polar cap, as it recedes during the Martian spring, was correlated with the terrestrial snow cover extent as measured during Earth's winter. Comparisons of the south pole of Mars and the south pole of Earth were not made because on Earth, in the southern hemisphere there are no large areas which are seasonally snow covered and thus, the maximum snow cover extent from year to year is nearly always the same.

RESULTS

Table 5 presents data on the observations of Mars north polar cap, annual sunspot numbers, and the Earth's snow cover extent for the northern hemisphere for the years 1916–1982. Measurements of Mars ice cap are given in degrees of latitude and were made during the Martian spring and early summer. The Martian spring equinox corresponds to ALS of '0' and the summer solstice corresponds to ALS '90'. As mentioned previously, observations cannot be made every year, and even those years when observations are possible, measurements generally cannot be made continuously throughout the Martian spring when the cap is receding. Values for annual sunspots are the average number of sunspots observed each day for the given year. Snow cover values represent the area of the Earth's surface in the northern hemisphere, in millions of square kilometers covered by ice and snow.

Table 6 gives coefficient of determination (r^2) values for the latitude of the north polar cap of Mars versus annual sunspot numbers. Because data for the Earth's snow cover are available only since 1966, they have not been included in this table. It is seen from Table 6 that the correlations between the width of Mars north cap and sunspot numbers is near zero at almost every ALS interval during the Martian spring.

Table 7 shows correlations between variations in the size of Mars north polar cap and the Earth's northern hemisphere snow cover, but only data from 1967–1982 is presented. Because the northern hemisphere of Mars was difficult to observe from Earth during the early and mid 1970's, only 6 years of data could be analyzed, and only those data for the Martian mid-spring period (ALS 50° - 70°) had complete data for all 6 years.

When regressing data for the Earth's northern hemisphere snow cover with the width of the Martian north polar cap an inverse relationship was found with r^2 values which ranged between 0.3 and 0.69. These correlations may well be spurious with so few data points even though they are statistically significant in some cases. The interpretation of the correlations in terms of cause and effect are by no means obvious, but it should be noted that the data sets include a wide range of measurements of the size of Mars' and Earth's polar caps for the past 20 years.

DISCUSSION

Although there are unquestionable year to year variations in the extent of the Martian polar caps, it should be reiterated that there are difficulties in making accurate measurements of the polar caps. Through the first half of this century, measurements were made from either simple visual estimates or photographic plates which are fairly crude compared to techniques used today which utilize direct measurements made with a filar micrometer attached to a telescope to map the retreat of the polar caps. Even though these methods are considered to be reliable, only with practice and attention to detail is a high degree of accuracy acquired (Parker et al. 1982). Aside from noise introduced by differences in instrumentation, some noise probably results from problems in distinguishing polar ice from haze or clouds early in the Martian spring, excluding small outliers or protrusions of ice from the overall polar cap measurement and the fact that the ice edge is sometimes obscured by dust in the Martian atmosphere.

It has been shown (Table 6) that there is little correlation between annual sunspot number and the width of the Martian north polar cap. However such a relation cannot be ruled out from theoretical considerations. Although changes in solar variation seem to have a cyclical character, changes related to solar cycles are expected to produce their own trends. This is because no two consecutive solar cycles are alike with respect to the level of solar activity. It could be that whatever relationship there is between solar activity and the size of the Martian polar cap is just not evident in the annual sunspot record. Also it should be noted that despite much research no connections between solar variations and climate on Earth have ever been unequivocally established. Apparent correlations have almost always faltered when tested with different data sets (Geophysics Research Board, 1982).

The climates of the planets are largely determined by their distance from the Sun. The relative nearness of Earth and Mars undoubtedly contributes to some of their physical similarities. They are the only planets in the solar system having polar caps which measonally expand and contract. But the Earth's climate is considerably more complex than that of Mars and the dynamics, orbital characteristics and energy transport mechanisms of the two planets are very different. So it is not unexpected that Earth's and Mars' polar caps do not fluctuate synchronously. There is no known plausible physical mechanism that can explain the inverse relationship noted here between annual variations in the size of the northern hemisphere polar caps of the two planets. It remains to be seen if the association will hold-up with a larger number of observations or will be confirmed by an independent data set. Regardless though, if the causes are not understood the circumstances that brought them about in the past cannot be used to determine if they will work similarly in the future.

CONCLUSIONS

Mars and Earth both have seasonal polar caps which expand and contract in accordance with their distance to the Sun and amount of solar radiation received. The dramatic change in ice and snow cover from one season to another is bound to have a considerable impact on the climates of both of these planets. No evidence has been found in this study to link solar variability to variations in the extent of the north polar cap of Mars. An inverse relationship was found between variations in the sizes of the polar caps of Earth and Mars but only 6 years of concurrent data was available for comparison, and no plausible mechanism exists to account for such a relationship. A longer period of record is needed to see if the correlations hold-up under more numerous observations. Unfortunately, the next opposition of Mars favorable for mapping the north polar cap will not occur until 1993.

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Table 1
Physical and Orbital Characteristics of Earth and Mars

Earth	Description	Mars
12,756 km	Diameter	6787 km
5.98×10^{24} kg	Mass	0.646×10^{24} kg
9.75 m/s^2	Gravitational acceleration	3.71 m/s^2
149.5×10^6 km (average)	Distance from Sun	227.8×10^6 km (average)
0.0167	Eccentricity	0.0933
839 cal/cm^2/day	Sunlight intensity	371 cal/cm^2/sol
23° 27″	Inclination (obliquity)	25°12′
24^h00^m	Rotational Period (Length of Day)	24^h40^m (= 1 sol)
365 days	Sidereal Period Length of Year)	686 days (668 sols)
60 000γ	Magnetic field	50–100γ
1013 mb (average)	Atmospheric pressure	7 mb (average)
1	Known satellites	2
0.30	Global albedo	0.17
29.8 kilometers per second	Orbital speed	24.1 kilometers per second

Table 2
Oppositions of Mars and Earth
(Related Mars Season When Opposition Occurs During a Given Earth Season)

Approaching season in Earth's Northern Hemisphere	Approaching season on Mars	
	North	South
Autumn	Winter	Summer
Winter	Spring	Autumn
Summer	Autumn	Spring
Spring	Summer	Winter

Table 3
Martian Seasons

Northern Hemisphere	Southern Hemisphere	Earth Days
Spring	Autumn	199
Summer	Winter	183
Autumn	Spring	147
Winter	Summer	158
	Total	687

Table 4
Composition of the Lower Atmosphere of Mars and Earth

Gas	Mars	Earth
	Concentration, %	Concentration, %
Carbon dioxide	93.32	0.03
Nitrogen	2.7	78.08
Argon	1.6	0.93
Oxygen	0.13	20.95
Carbon monoxide	0.07	<0.01
Water vapor	0.03	<4.0
Neon	2.5 ppm	18.8×10^{-4}
Krypton	0.3 ppm	1.14×10^{-4}
Xenon	0.08 ppm	0.087×10^{-4}
Ozone	0.03 ppm	$<0.07 \times 10^{-4}$

Table 5
Latitude of Mars North Polar Cap (in degrees) During the Martian Spring

Year	Martian Seasonal Date (ALS in degrees)									
	30	40	50	60	70	80	90	100	110	120
1982			64	69.5	73	79	84	83.5	84.5	83.5
1980	57.5	62	64	66.5	74	78	82.5	83		
1978	66	67	69	70.5	73.5					
1969			54	55	57.5	64	74	76	75	77
1967	59	61.5	62	64	67	70	75	79	82	84
1965		60.5	63.5	67	74	79	78	79	80	81.5
1963		63	66	72	73	74.5	77	78.5		
1952										79
1950					70.5	82	81.5	81	87	86
1948		64	67.5	70.5	75					
1946	61	61.5								
1935								83	82	82
1931		65.5	66.5	66						
1930	66.5									
1920										81.5
1916			68.5	69.5	70.5					

Table 5 (continued)

Year	Earth's NH Snow Cover			Annual Sunspots
	Dec.-Feb.	Jan.	Annual	
	In millions of km^2			Avg. number for each day of the year
1982	45.2	47.5	25.0	116
1980	44.0	45.0	25.8	155
1978	49.3	50.4	28.3	92
1969	43.1	43.4	23.8	106
1967	42.5	44.0	23.4	94
1965				15
1963				28
1952				32
1950				84
1948				136
1946				92
1935				36
1931				21
1930				35
1920				37
1916				57

Table 6
r^2 Values of Mars North Polar Cap Extent Throughout the Martian Spring Season Versus Sunspot Number

	1916-1982									
	Martian Seasonal Date (ALS in degrees)									
	120	110	100	90	80	70	60	50	40	30
Annual Sunspot Number	0.03	0.00	0.07	0.15	0.01	0.00	0.03	0.04	0.01	0.61

Table 7
r^2 Values of Mars North Polar Cap Extent Throughout the Martian Spring Season Versus Earth's Snow Cover

	1967-1982									
	Martian Seasonal Date (ALS in degrees)									
	120	110	100	90	80	70	60	50	40	30
Northern Hemisphere Average December - February Snow Cover of the Earth	-	-	-	-	-	0.30	0.45	0.56	-	-
Northern Hemisphere Average January Snow Cover of the Earth	-	-	-	-	-	0.45	0.64_s	0.69_s	-	-
Northern Hemisphere Average Annual Snow Cover of the Earth	-	-	-	-	-	0.42	0.46	0.62	-	-

s = significant at 0.05 level
- = less than 5 data points

Correlations (r values) are negative

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Figure 6. Plot showing width of Martian north polar cap at ALS 50° versus Earth's average January snow cover area for the northern hemisphere from 1967–1982.

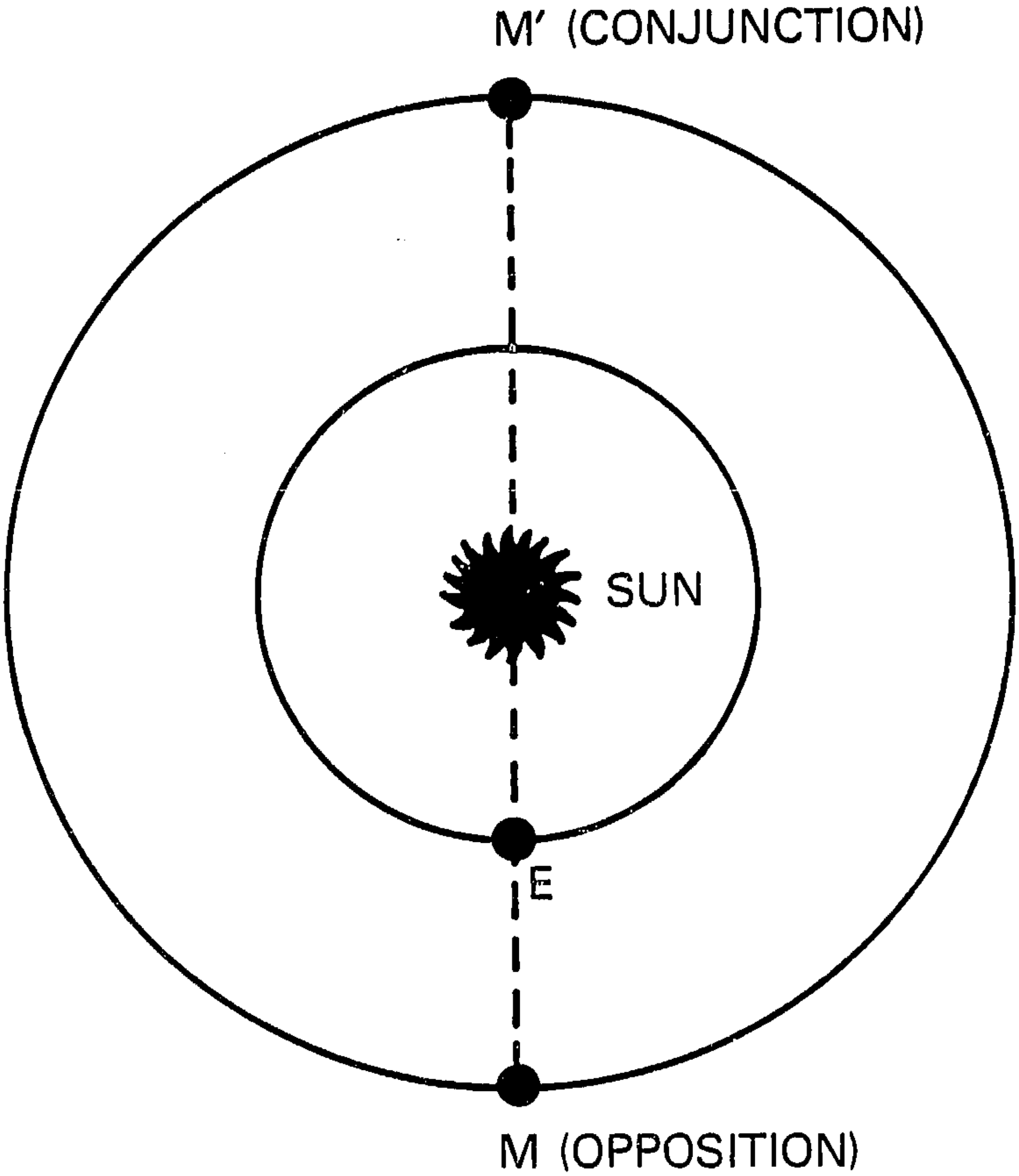


Figure 1. Mars at conjunction and opposition

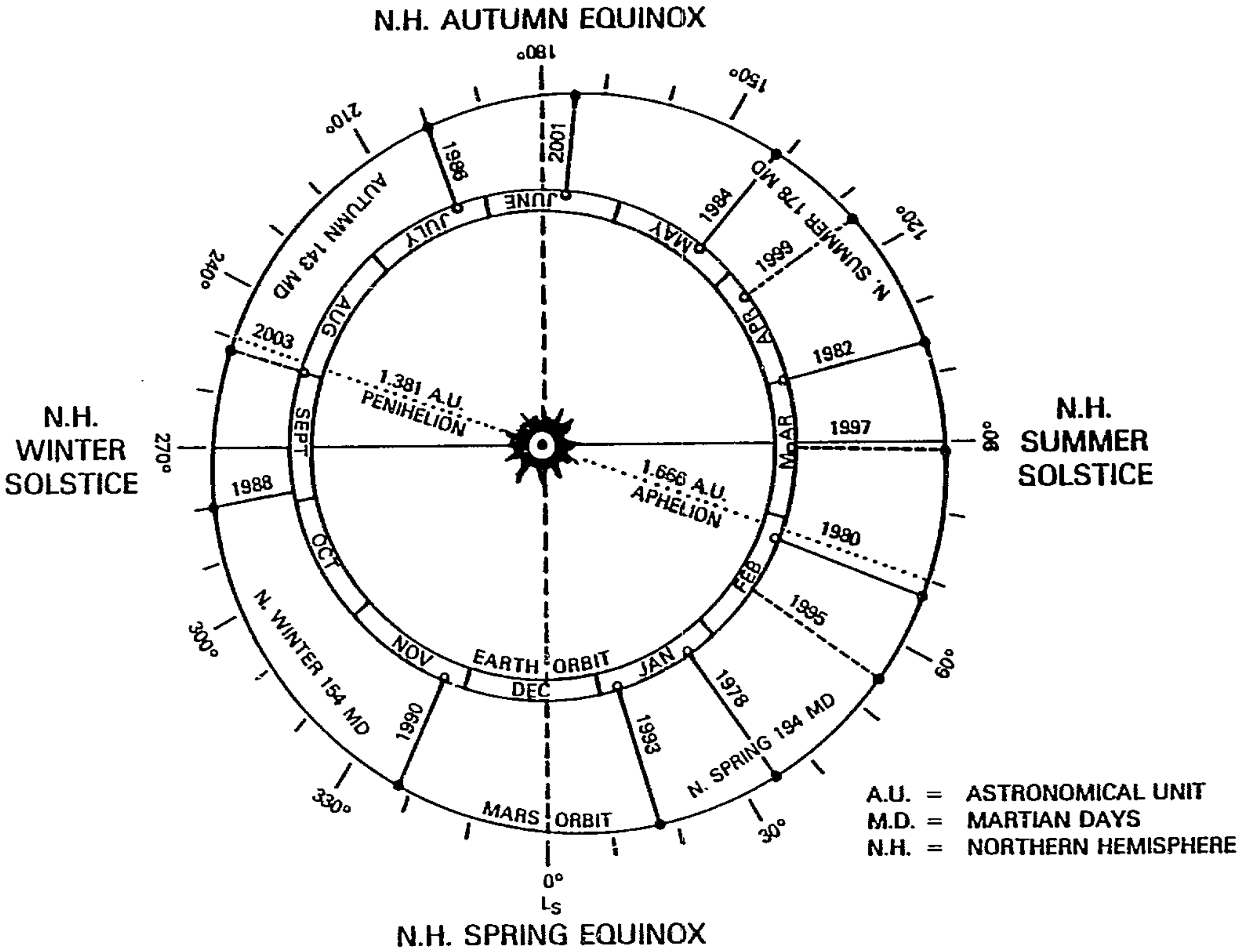
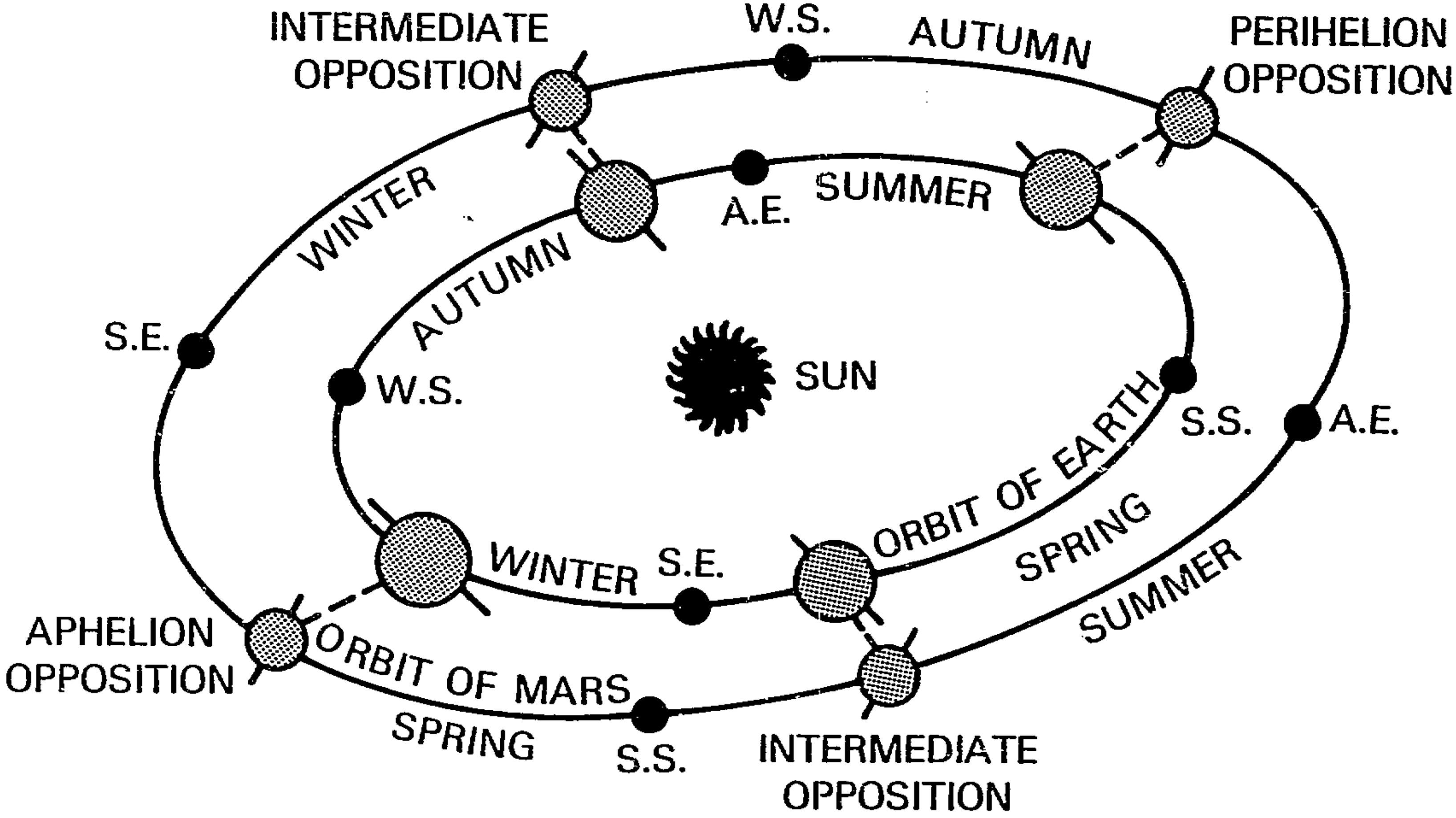


Figure 2. Oppositions of Earth and Mars from 1978–2003. The Areocentric System (LS) defines in degrees the Martian seasonal date.



SE = SPRING EQUINOX SS = SPRING SOLSTICE
AE = AUTUMN EQUINOX WS = WINTER SOLSTICE

Figure 3. Direction of axes of Earth and Mars at various oppositions

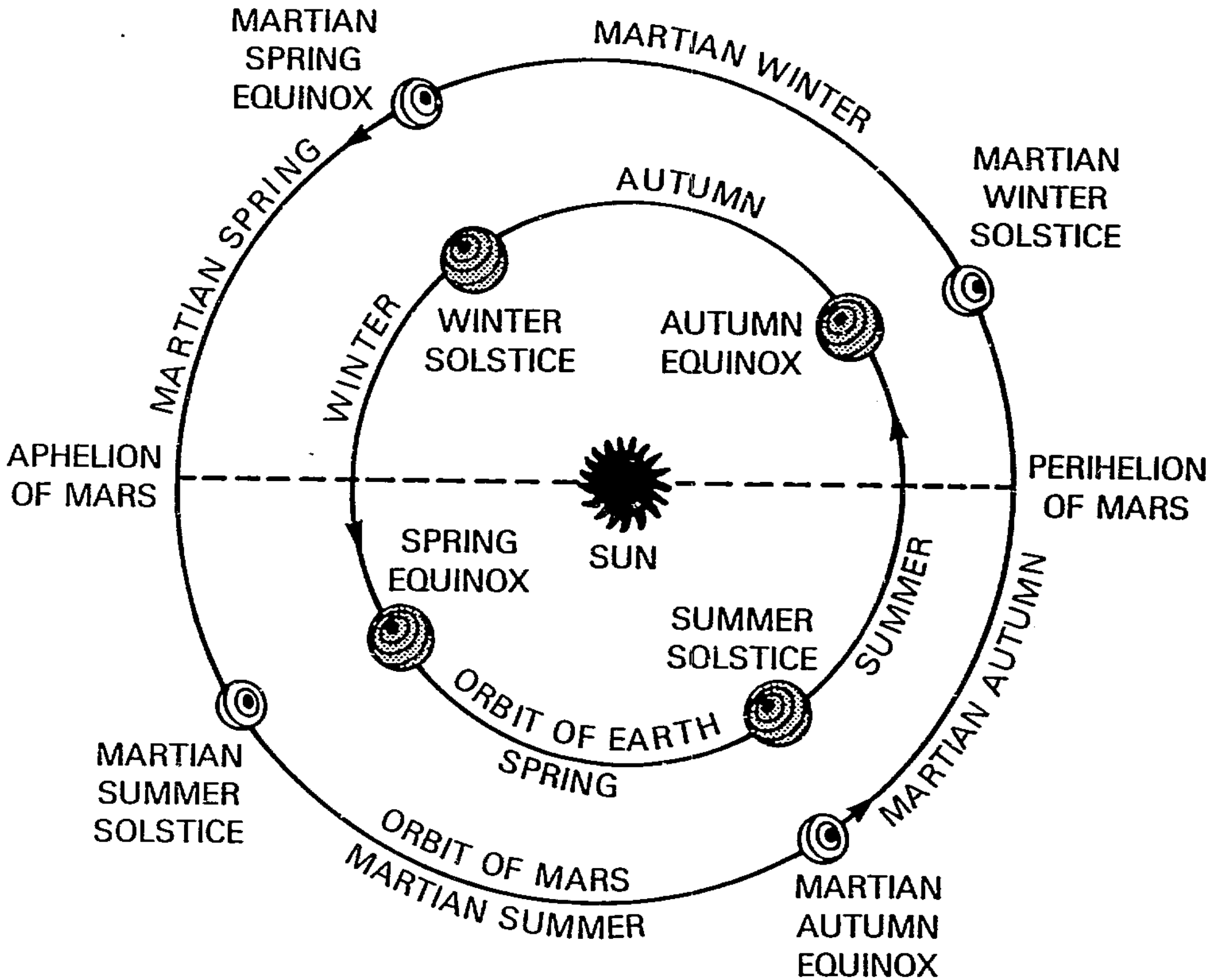


Figure 4. Seasons of Earth and Mars

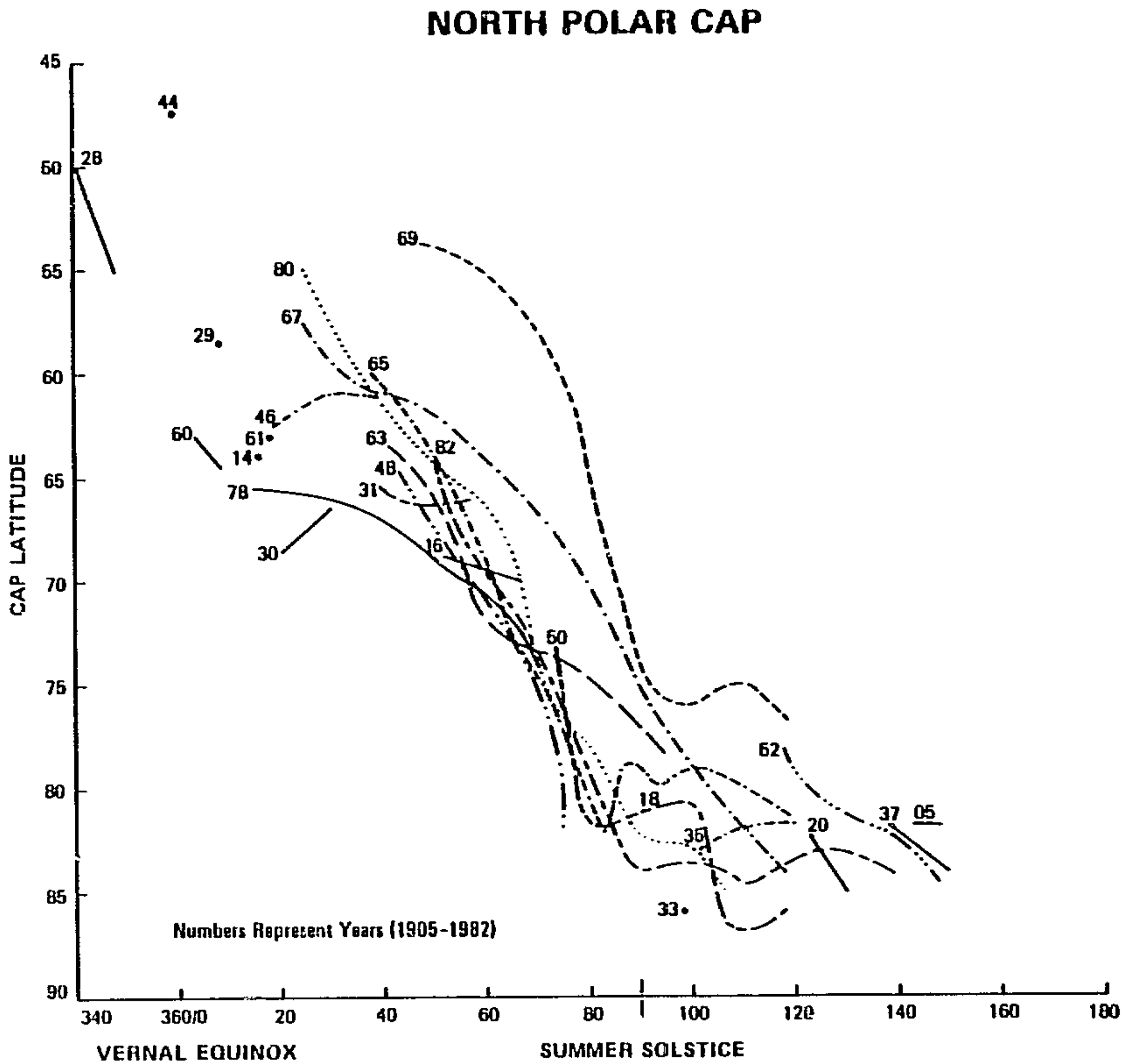


Figure 5. Plots of the Mars northern polar cap recession during the Martian spring from 1916–1982

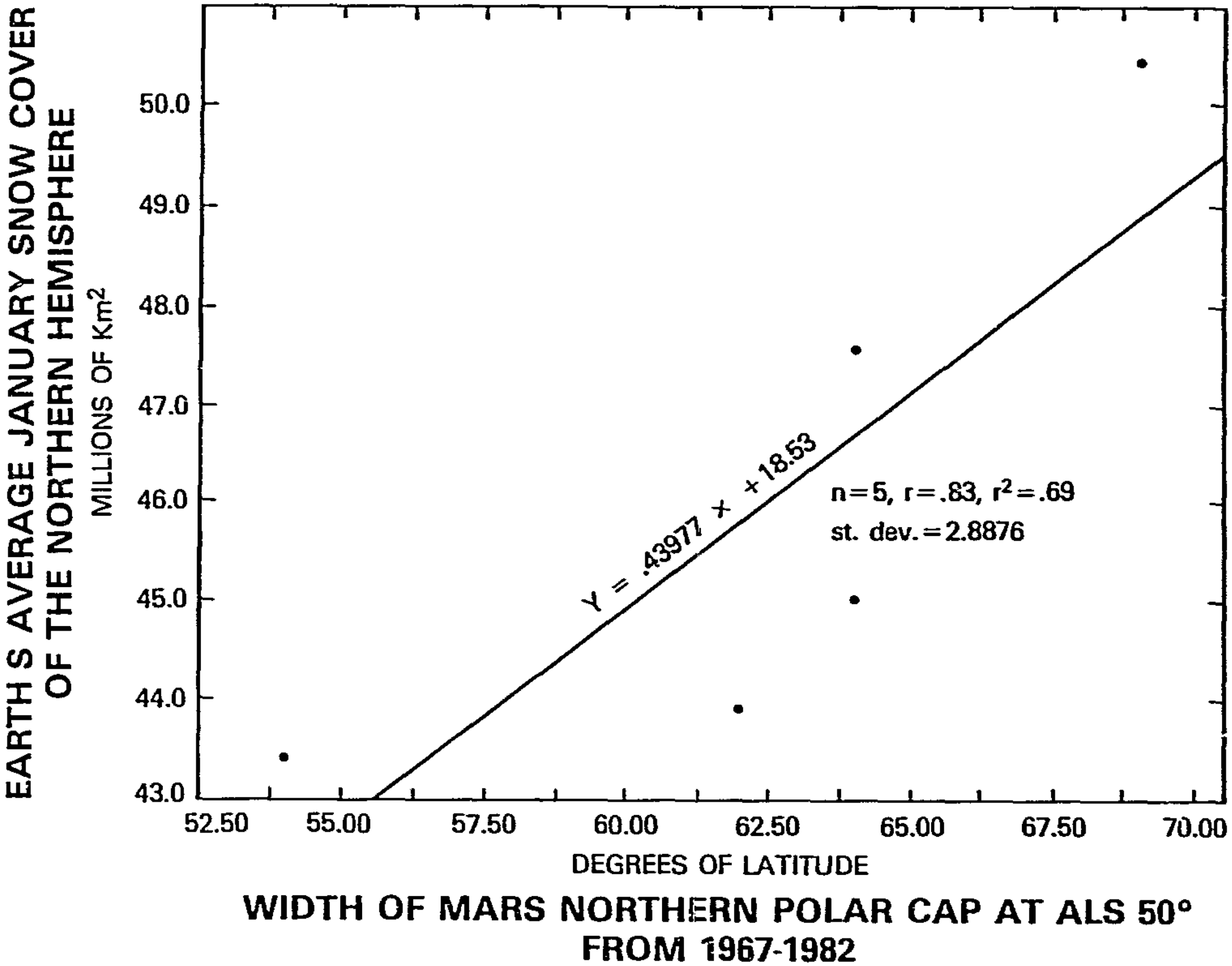


Figure 6. Plot showing width of Martian north polar cap at ALS 50° versus Earth's average January snow cover area for the northern hemisphere from 1967–1982

ADDENDUM
(1984 Data)

Latitude of North Polar Cap of Mars During Martian Spring

Martian Seasonal Date (ALS in degrees)

1984	50	60	70	80	90
	60°	64°	73°	73°	79°

Earth's Northern Hemisphere Snow Cover in millions of km² (Avg)

1984	Dec.-Feb.	Jan.	Annual
	45.2	45.5	24.1

Annual Sunspot Number

1984	46

r^2 Values 1967-1984

	Martian Seasonal Date (ALS in degrees)		
Earth's Northern Hemisphere Avg. Snow Cover	70	60	50
Dec.-Feb.	30	43	49
Jan.	39	64_s	70_s
Annual	30	45	64

NOTE: Correlations (r values) are negative.
s = significant at 0.05 level.

BIBLIOGRAPHIC DATA SHEET

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16. Abstract

The boundaries of the polar caps of Mars have been measured on more than 3000 photographs since 1905 from the plate collection at the Lowell Observatory. For the Earth the polar caps have been accurately mapped only since the mid 1960's when satellites were first available to synoptically view the polar regions. The polar caps of both planets wax and wane in response to changes in the seasons, and interannual differences in polar cap behavior on Mars as well as Earth are intimately linked to global energy balance. In this study data on the year to y variations in the extent of the polar caps of Mars and Earth were assembled and analyzed together with data on annual variations in solar activity to determine if associations exist between these data. It was found that virtually no correlation exists between measurements of Mars north polar cap and solar variability. An inverse relationship was found between variations in the size of the north polar caps of Mars and Earth, although only 6 years of concurrent data were available for comparison.

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